January 28, 2014

Sudden Aspen Decline

Report for

Spruce Beetle Epidemic and Aspen Decline Management Response EIS

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Background

Aspen is an important component of GMUG's forests. Over 288,000 ha (712,000 acres) of aspen-dominated forest type (TAA) occur across the GMUG (Table 1). Just over half (55%) of the aspen forest type is outside wilderness and roadless areas.

Table 1. Area (ha) of aspen forest type (TAA) on the GMUG. Provided by Cheryl O'Brien, GMUG SO.

Ranger District	All	Outside Wilderness/ Roadless
Grand Valley	60,153	31,807
Gunnison	77,183	42,774
Norwood	26,985	23,705
Ouray	43,215	37,266
Paonia	80,532	23,126
TOTAL	288,068	158,679

Importance of aspen

Aspen is a unique and important tree species in western North America, where aspen is the most diverse upland forest type. Of roughly 1669 species of wood-decay fungi tallied in North America, Gilbertson (1980) noted 260 on aspen, more than on any other tree species, and many of which are specialized on aspen. Similarly, in Fennoscandia, aspen is a critically important host and substrate for lichens, polypores, and hundreds of invertebrates, including dozens of threatened saproxylic beetles (Kouki *et al.* 2004). Bird species richness and total abundance are higher in aspen stands than in other North American montane habitats (e.g., Turchi *et al.* 1995), and many species show strong preferences for aspen trees or forests for nesting habitat (Flack 1976). Aspen modifies soil properties and microclimate in ways that foster luxuriant growth of varying herb and shrub layers. These forests are therefore major contributors to plant species diversity, and plant diversity decreases drastically during succession to conifers (Kuhn *et al.* 2011, Mueggler 1985). The importance of aspen communities to large ungulates such as elk is well known, and in dry forest ecosystems, patches of aspen are also hotspots of diversity for small mammals (Oaten & Larsen 2008). Thus, aspen is truly a keystone species, and as such its loss leads to substantial alteration of habitat conditions and loss of species diversity.

Aspen modifies hydrological dynamics in ways that benefit biota and streamflow, an important parameter in the arid West. Abundant undergrowth and litter prevent erosion and increase infiltration, while increased soil organic matter improves water-holding capacity. Results of modeling based on rates of water movement by season in various tree species suggested significantly greater water yield from aspen than from conifer forests (Gifford *et al.* 1984). This was confirmed more recently (LaMalfa & Ryel 2008). Although annual evapotranspiration can be higher in aspen than in conifer forests, it is more than offset by the higher storage of water in the snowpack and soil.

In addition, aspen forests have significant economic value based on tourism and fiber production. Esthetically, aspen contribute a major share of Colorado's scenic beauty. Tourism is the second largest industry in Colorado, with tourists spending $17 billion in the state in 2012 (Tourism Pays, Denver Convention and Visitor Bureau). During the recent episode of sudden aspen decline (SAD), leaders of several mountain communities in Colorado expressed concern in interviews that deterioration of aspen could significantly affect tourism income. The properties of aspen wood make it valuable for paneling, oriented strandboard, and excelsior (used in erosion control and oil-spill cleanup), all of which are or were produced in southwestern Colorado.

Finally, aspen forests, like other forest types, store considerable carbon in above- and belowground biomass (and especially for aspen, in the soil). As aspen stands mature and regenerate, there is a cycle of carbon release and sequestration with a high net storage of carbon. If aspen forests are replaced by shrub or meadow communities with lower carbon storage capacities, the difference will contribute to atmospheric CO_2. Aspen mortality episodes in the aspen parkland of Alberta and Saskatchewan and in southwestern Colorado are expected to result in significant carbon release and positive feedbacks to climate change (Huang & Anderegg 2012, Michaelian *et al.* 2011). For carbon storage, it is important that we maintain forest cover wherever possible.

Sudden aspen decline

Sudden aspen decline was first noticed in southwestern Colorado in 2004 (Worrall *et al.* 2008). On the San Juan National Forest, large and growing patches with crown thinning, branch dieback, and mortality were found. It was clear that this was not the usual stand-level cohort maturation and breakup that foresters have always seen. It occurred on a landscape scale and rapidly increased in area and severity. Over the next few years, SAD spread to the Uncompahgre Plateau, the Grand Mesa, and the Gunnison River basin. Aspen throughout Colorado was affected. In 2008, the year when the maximum area of SAD was mapped by aerial survey, over 220,000 ha were affected in Colorado (Worrall *et al.* 2010). About 45% of that area was rated as "severe", indicating estimated mortality over 50% of the overstory.

From 2000-2010, 535,000 ha were impacted by SAD in the Southern Rocky Mountains ecoregion, with 492,000 ha in Colorado (an estimated 17% of the aspen cover type in the state) (Worrall *et al.* 2013). The GMUG was affected much more severely: 33% (over 96,000 ha) of the GMUG's 288,068 ha of aspen cover type was affected from 2000 to 2010. In 2009, the detection of new areas dropped considerably, and little new area has been mapped since then.

A ground survey in 2007 and 2008 sampled the entire GMUG and the Mancos-Dolores Ranger District of the San Juan National Forest (Worrall *et al.* 2010). Areas identified as SAD by aerial survey had an average 54% recent crown loss and 45% mortality. SAD plots had higher root mortality than healthy plots (Worrall *et al.* 2010), and regeneration counts showed no evidence of increased suckering in response to the overstory damage (Dudley 2011, Worrall *et al.* 2010). This raised concern that the hardest hit stands could fail to regenerate themselves. Indeed, some patches of aspen at the lower-elevation fringe were completely dead with no regeneration. Remote sensing over 2009-2011 suggested that 30% of the total aboveground aspen biomass was dead in a large section of southwestern Colorado, with the resulting carbon emissions expected to provide an amplifying feedback to climate change (Huang & Anderegg 2012).

Although the cause of SAD was initially a mystery, attention quickly focused on moisture stress that preceded the onset of SAD. Damage was highest at low elevations, where temperature is high and precipitation is low (Dudley 2011, Worrall *et al.* 2008). Damage tended to be high on south- and west-facing slopes and on the shoulders and summits of slopes (Huang & Anderegg 2012, Worrall *et al.* 2008). Even under normal conditions, decline sites lay at the fringe of aspen's climate niche (Rehfeldt *et al.* 2009). But southwestern Colorado had a drying trend from the mid-1980s to 2002, culminating in a record drought in much of Colorado (Pielke *et al.* 2005). The most unfavorable climate in the record occurred in 2002, with many stations reporting record high summer temperatures and the lowest aspen-year precipitation on record. Areas with SAD had lower values of climate moisture index during 2002 than did aspen areas that remained healthy (Worrall *et al.* 2010). Various moisture indices showed that the area underwent a protracted, severe moisture deficit (Worrall *et al.* 2013). Climatic suitability for aspen generally decreased around the time of SAD, and SAD tended to occur in marginal sites where suitability decreased the most (Fig. 1).

The evidence that severe, warm drought incited SAD was clear and overwhelming, but a broader view gives a more comprehensive concept of the cause. As noted above, areas were predisposed to drought impact by site factors such as low elevation, south-facing slopes, and marginal local climate during normal conditions. Stand conditions, especially low density and openness, may have also predisposed stands to damage. At the other end of the causal chain, it was clear that drought did not kill the trees alone. Various insects and pathogens, often called secondary agents, can take advantage of stress to invade and kill the host. In this case, aspen bark beetles, bronze poplar borer, poplar borer, and Cytospora canker killed trees that had been stressed by drought (Marchetti *et al.* 2011). Thus, the predisposing and contributing factors played important roles, in addition to the inciting factor, drought.

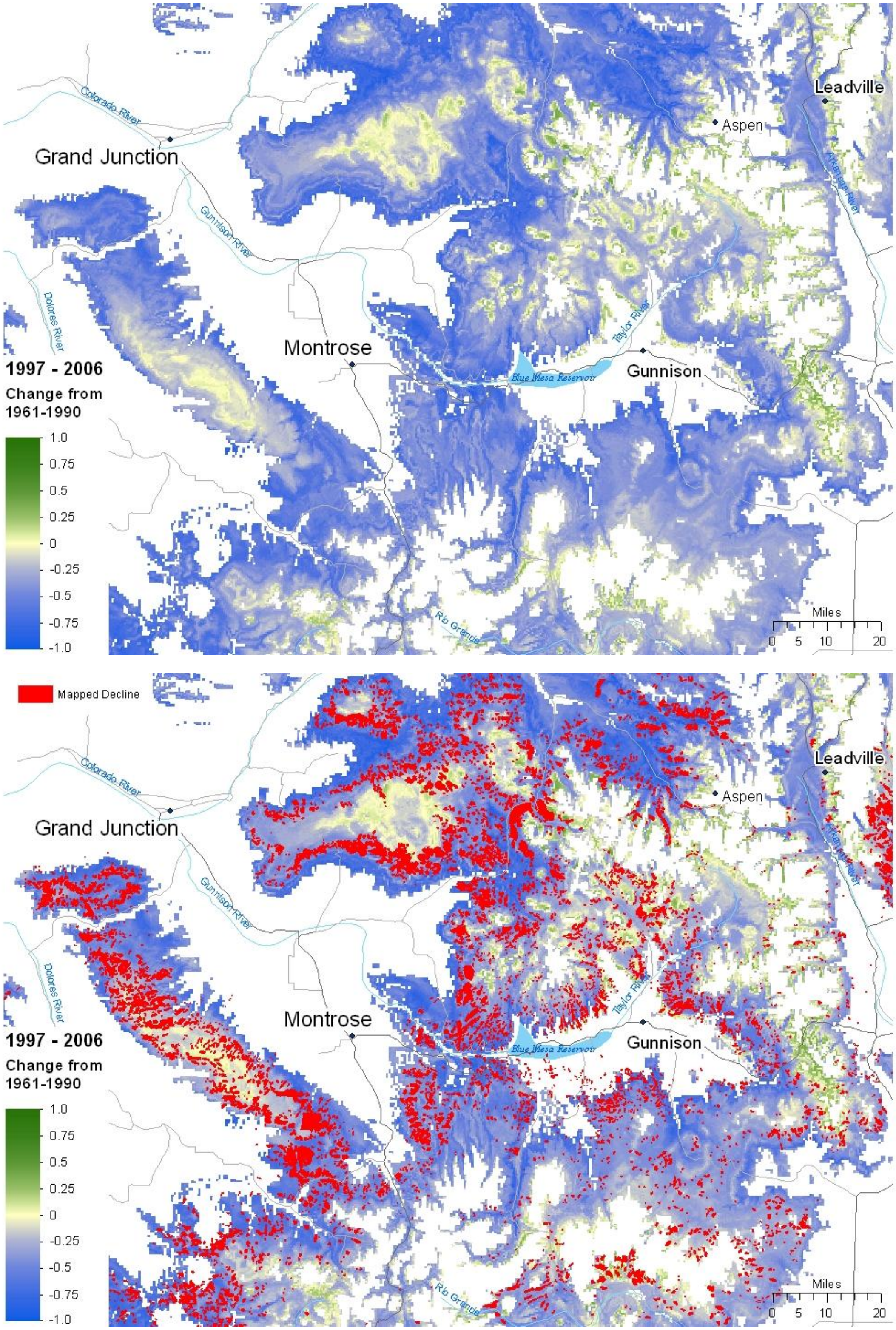

Figure 1. Top: Change in climatic suitability for aspen between the reference period, 1961-1990, and the decade preceding and accompanying the recent episode of SAD, 1997-2006 (provided by Andreas Hamann, Univ. Alberta). Blue indicates decrease in suitability; green an increase. Bottom: Same as Top, but with polygons of SAD mapped by aerial survey from 2000-2010 (Worrall *et al*. 2013). SAD tended to occur where climate suitability decreased (blue areas do not necessarily have significant aspen).

SAD vs. "Aspen Decline"

As described, sudden aspen decline is a rapid, landscape-scale deterioration of overstory aspen incited primarily by drought and warm temperatures. It is often confused with an older concept of "aspen decline". The latter refers to a long-term (over many decades) decrease in the area of aspen cover type (Bartos 2001, Bartos & Campbell 1998). The word "decline" in that case refers only to the area of aspen cover. This is primarily due to succession. Factors that have been suggested to lead to it include a large increase of aspen area associated with fires during the time of European settlement, subsequent fire exclusion, and excessive herbivory by large populations of ungulates (Bartos & Campbell 1998, Kulakowski *et al.* 2004).

There have been controversies over the need to apply management to reverse this traditional "aspen decline" (and even its very existence), both among scientists and in forest management planning and scoping. For example, some argue that it is a natural decrease in area of aspen that should be expected after the artificial increase of the late 19th century. However, that debate is not relevant to SAD, which has completely different origins and issues.

Current Condition of Aspen

The spread of SAD to new areas largely ended in 2009, and since then only very small areas have been mapped. Thus, on the GMUG, about 2/3 of the aspen cover type (not affected by SAD) is generally in good condition.

In 2013, we remeasured our original plots from 2007/08 (Worrall *et al.* 2010) to assess the aftermath of SAD in terms of overstory condition and regeneration (unpublished). The analysis indicated significant loss (between the two measurements) of live density and basal area for sick plots but not for healthy plots. Compared to healthy plots, sick plots continue to have much lower live density and basal area, and much higher recent dead density, snag density, recent dead basal area, and recent crown loss. This indicates that SAD-affected stands continue to deteriorate. In regeneration, healthy plots are doing well and significantly increased successful suckering (density of regeneration up to breast height). In contrast, sick plots significantly decreased in this regeneration measure (Fig. 2). Of 79 sick plots, 11 had no small regeneration (up to breast height) in 2013 and 36 plots (46%) had ≤ 300 stems/ha (≤120 stems/acre).

Future Condition: No Action

The 2013 plot remeasurement showed that overstories in stands affected by SAD continue to deteriorate while production of suckers has decreased. This trend will likely continue as stands become more open and stand microclimate becomes drier. Many of the severely affected stands may convert to another cover type over time, likely shrub-dominated vegetation at low elevations. In less severely affected stands, aspen will likely persist, though in some cases at lower density than before.

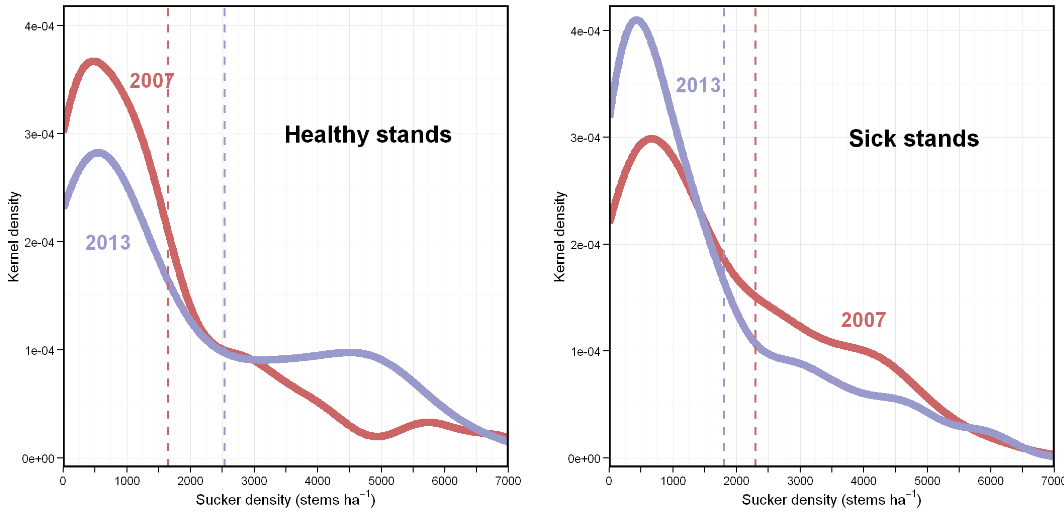

Figure 2. Frequency distribution of small sucker density among healthy and sick aspen stands on the GMUG and western SJNF in 2007/08 vs. 2013, based on sample of 160 plots. Healthy stands shifted to higher sucker density; sick stands to lower. Both changes were significant. Vertical dashed lines are the mean sucker densities. Sick stands are those which experienced substantial mortality and crown loss from 2002-2007. Small suckers are ≤ 1.4 m tall. Larger size classes of regeneration did not change significantly. Kernel density is an estimate of the relative frequency of sucker density values in the population based on the sample.

Aside from the aftermath of the recent episode, we can expect more episodes of SAD in the future due to climate change. This is partly because of the increasing trend of temperature and dryness that is projected, but more importantly because of projected increases in frequency of extreme weather, especially drought (Ray *et al.* 2008). Forests respond primarily to climatic extremes, not the long-term trend of climate.

Based on studies described above, we now can predict with some confidence what these future episodes will look like, what kinds of sites and stands they will likely occur in, and in general what their impacts will be. The models project rapidly deteriorating climatic suitability for aspen in the Southern Rockies through the rest of the century (Fig. 3). These models suggest that, even in many better aspen habitats that were not affected in the recent episode, suitability will decrease well below the levels that were associated with that episode. It seems clear that there will be complete loss of aspen in some lower-elevation sites and on south slopes, while at the other extreme, aspen habitat will persist and even become newly suitable at higher elevations and north slopes.

The recent SAD episode followed closely the projected change in climate suitability for aspen, and that suitability actually decreased in affected areas in the decade preceding and accompanying the damage (Rehfeldt *et al.* 2009, Worrall *et al.* 2013). Thus, the recent episode of SAD is consistent with modeled effects of climate change on aspen and can be considered a first wave of impacts to aspen.

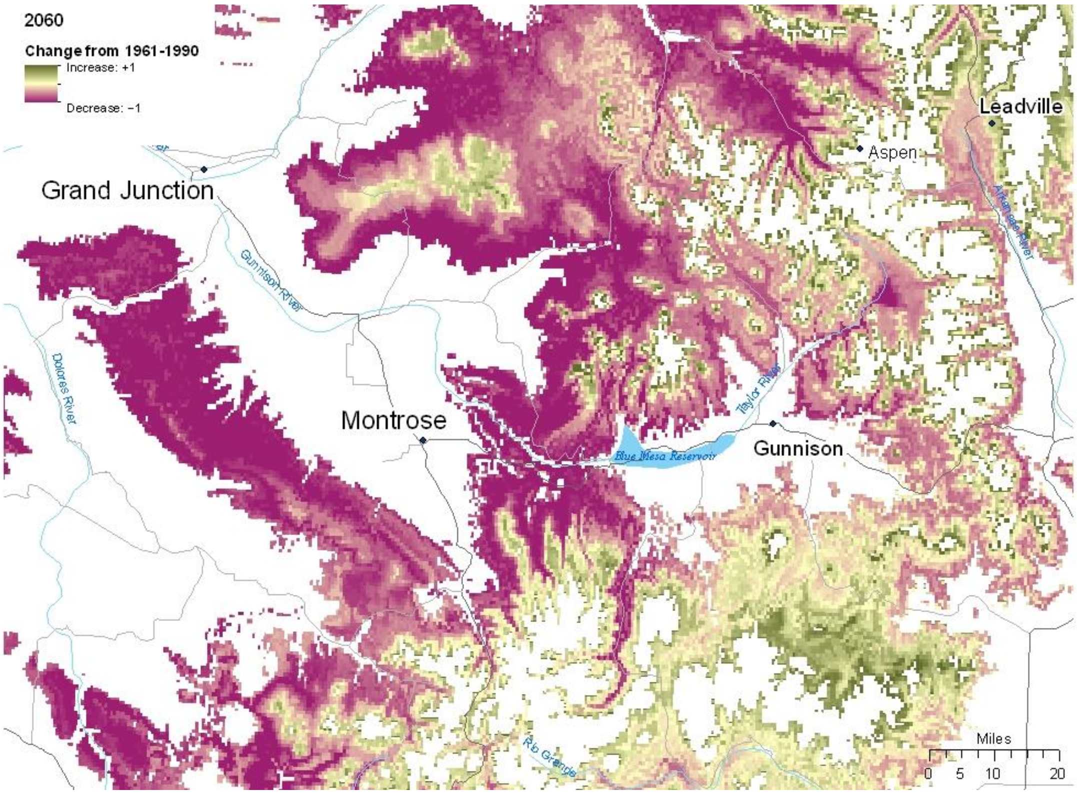

Figure 3. Projected change in climatic suitability for aspen between the reference period (1961-1990) and the decade surrounding 2060. Maroon indicates decrease in suitability; green an increase. Based on the aspen bioclimate model (Jerry Rehfeldt, RMRS) and climate projections using the RCP-6.0 carbon scenario in three general circulation models (GCMs); map is the average of the three projections.

Management Tools and Tactics

In practice, there are two tools for managing aspen, fire and mechanical removal. Healthy aspen generally sprouts profusely from the roots when the overstory is killed by cutting or burning, regenerating the stand (Jones & DeByle 1985, Shepperd 1993). Recent studies suggest three major tactics for management of aspen as the climate changes:

1. Recovery

Declining stands already affected by SAD can recover if regenerated before about half the overstory dies. In southwestern Utah, on Cedar Mountain, coppice harvest was conducted in stands at different levels of mortality (Ohms 2003). Regeneration response was good when overstories had less than about 50% mortality, but dropped to near 0 above that point (Fig. 4). Similarly, in the Terror Creek watershed north of Paonia on the Gunnison National Forest, an Applied Silvicultural Assessment was conducted to test the regeneration response of SAD-affected stands (Shepperd & Smith 2013). Regeneration density after cutting was strongly associated with SAD severity (Fig. 5), and was correlated with the residual live basal area in the overstory before cutting. Although Terror Creek has higher levels of pre-harvest regeneration than southwestern Colorado as a whole (see Current Condition of Aspen), this is consistent with the Utah study and supports recovery of declining stands through regeneration.

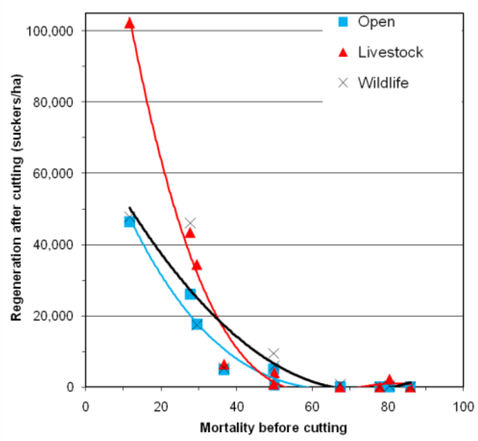

Figure 4. Regeneration response following coppice harvest of aspen stands with different mortality levels in southwestern Utah (data from Ohms 2003).

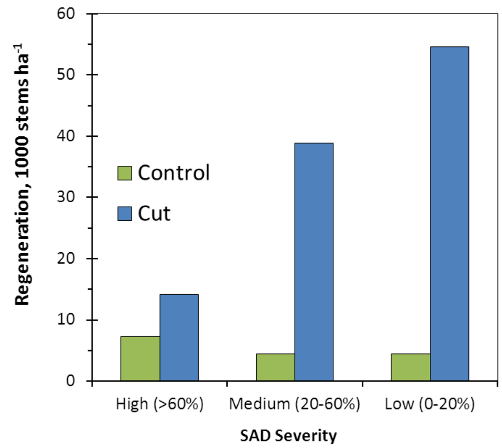

Figure 5. Regeneration following coppice harvest of stands with varying SAD severity in the Terror Creek Applied Silvicultural Assessment (data from Shepherd & Smith 2013).

2. Resilience

During the recent SAD episode, young stands were unaffected even as residual overstories around them died (Worrall *et al.* 2010; Fig. 6). These young stands, less than about 40 years old, were more resilient to drought. Thus a second adaptive tactic would be to increase resilience of aspen to drought by ensuring that there are significant patches of aspen under 40 years old on the landscape. This would more closely resemble what some ecologists have suggested was the presettlement condition of aspen in some areas, when fires more often killed and regenerated it before it reached maturity (Binkley *et al.* 2006, Margolis *et al.* 2011).

Figure 6. Surrounded by dead and dying residual overstory, the 34-yr old, coppice-harvested patch in the center of the photo was unaffected by SAD. Terror Creek watershed, Paonia Ranger District, Gunnison NF, 2007.

3. Migration

We can facilitate migration of aspen into areas that become newly suitable as the climate changes. Although female aspen often produce prolific crops of seeds, it was once thought that that seedlings become established only rarely, and that sexual reproduction has not occurred on any large scale since the retreat of the Wisconsin glaciation. New genetic evidence and more careful observations show that seedlings become established frequently, and that frequency is ecologically important (Long & Mock 2012). Seedlings have been found as far as 15 km from mature aspen (Turner *et al.* 2003). In another study, seedlings were found 8 km from the nearest mature aspen, but 18 km in the direction of prevailing winds (Landhäusser *et al.* 2010). Median dispersal distances are probably substantially less than these. Heavy mechanical or fire disturbance is usually necessary, and the best seedbed is exposed mineral soil. Already, on the Gunnison and San Juan NFs, observations suggested limited migration of aspen up in elevation via seed on southern aspects since 1900, mostly since 1950 (Elliott & Baker 2004). Direct evidence of recent migration was obtained in Alberta, where researchers found aspen seedlings becoming established at elevations higher than aspen occurred previously (Landhäusser *et al.* 2010). This upward migration was facilitated by the increasing trend of temperature and harvest of the existing conifer stand.

Protection of aspen regeneration from herbivory

When ungulates, most commonly elk, are abundant in an area, regeneration following fire or cutting of aspen is frequently threatened by browsing (Dieni *et al.* 2000, Romme *et al.* 1995). In some cases, a regenerating stand may be consumed so completely for several years that the root system expends all its resources and dies, so that aspen does not return to the site (Bartos *et al.* 1994, Bartos & Campbell 1998, Bartos *et al.* 1991, DeByle 1985, Kay 2001). In such cases, there are three approaches to reducing the impact:

Fencing. If fences are high enough, strong enough, and are maintained for long enough, they are highly effective at protecting regeneration (Dieni *et al.* 2000, Rolf 2001). However, they are quite expensive.

Overwhelming amounts of regeneration. Extensive, scattered areas of regeneration may effectively overwhelm the ability of herbivore populations to consume it. Although this is sound in principle (Gruell 1980), apparently it did not work following the extensive Yellowstone wildfires of 1998 (Kay 2001, Romme *et al.* 1995), perhaps because of the extremely high elk populations that overwinter there.

Reducing herbivore populations. In the long run, this may be the most effective and least expensive approach to protecting regenerating aspen from herbivory (Binkley 2008, Kay 2001). However, it is politically challenging, and experience has shown that substantial reductions may be needed (Fairweather *et al.* 2008, Rolf 2001). Introduction of wolves as elk predators has also been suggested to improve aspen recruitment (Ripple & Beschta 2011), but evidence that it is effective has been challenged (Kauffman *et al.* 2010, Kimble *et al.* 2011).

A Strategy for Adaptation of Aspen to Climate Change

Climate change adaptation in forest ecosystems is primarily focused on managing the forest to reduce vulnerability and enhance recovery (Spittlehouse & Stewart 2004). We now have the knowledge to develop a strategy to do that with aspen.

1. Classify aspen habitat by change in climate suitability

Aspen management approaches will vary, depending on the anticipated impacts of climate change on aspen. Thus, it is necessary to classify aspen habitat geographically on this basis. Management can then be tailored to these zones. The following four classes are based on projected changes in climatic suitability for aspen:

LOST HABITAT – future climate will be so unfavorable that aspen is unlikely to survive the century. In general, do not treat to manage aspen (but see section 3 below).

THREATENED HABITAT – future climate will be unfavorable, but young stands will probably survive. Treat to distribute young patches on landscape and to help SAD stands recover.

PERSISTENT HABITAT – future climate will remain suitable for aspen. No climate-change adaptation needed, but normal management may proceed. Promote existing aspen near EMERGENT habitat.

EMERGENT HABITAT – areas outside current distribution that will become climatically suitable. Allow or create disturbance (fire or mechanical) to facilitate migration.

The classification methods we followed are based on Rehfeldt's bioclimate model (Rehfeldt *et al.* 2009, Worrall *et al.* 2013). The bioclimate model was initially developed by taking as input hundreds of thousands of locations with known presence or absence of aspen, and used regression trees to associate presence or absence with long-term mean climate variables from the reference period, 1961-1990, at each location. In this way, the climate values that are associated with presence of aspen were determined.

Then the model was provided with a continuous grid of climate variables and asked to rate the climatic suitability of each cell for aspen. Based on thousands of randomized model runs, the ouput is a grid of "vote" percentages. A grid cell with very few votes is extremely unfavorable for aspen and has virtually no chance of having aspen; while very high votes indicate a climate ideal for aspen and high likelihood of having it.

The bioclimate model provided a distribution of votes in the reference period that closely follows the known distribution of aspen (Rehfeldt *et al.* 2009, Worrall *et al.* 2013). When the actual climate of 1997-2006 was used as input, the bioclimate model showed substantial decreases in climatic suitability where aspen declines occurred in western North America from

2000-2010. These relationships indicate the reliability of the model in assessing climate suitability for aspen.

Downscaled climate projections from general circulation models (GCMs) can also be used as input for the bioclimate model. Such climate projections are based in part on greenhouse-gas-emissions scenarios. Three representative GCMs and the A2 scenario from the IPCC Assessment Report 4 (AR4) have been used with the aspen bioclimate model in recent publications. In the work for this EIS, we used a newer emissions scenario that was developed and used for IPCC AR5, called RCP-6.0. Although officially no RCP (representative concentration pathway) is considered more likely than another, this one is the middle of the three RCPs that are considered within the realm of possibility and represents a moderate scenario. It is more conservative than the A2 scenario used earlier: it results in projection of substantially lower global temperatures than does A2 (Rogelj *et al.* 2012).

To develop the four climatic habitat zones for aspen, we first used a vote threshold of 50% to indicate suitable (≥ 50%) and unsuitable (< 50%) climate for aspen. This provided a close approximation to the known distribution of aspen in the GMUG and surrounding areas. Thus the LOST aspen habitat is represented by grid cells with votes ≥ 50% in the reference period, and < 50% in 2060. Similarly, the EMERGENT zone is comprised of grid cells with votes < 50% in the reference period, and ≥ 50% in 2060.

The remaining aspen habitat had votes ≥ 50% in both periods. In this zone, votes may be relatively low at both ends of the climatic spectrum: the climate is tending toward either too warm and dry or too cold and wet for aspen. We would not consider the latter case threatened, as it is likely to increase in suitability as the climate continues to change. Therefore, rather than using votes to split this middle zone, we used $MMAX_{2060}$, the mean temperature of the warmest month in the decade surrounding 2060. This was the most important variable in the bioclimate model. Sites with high MMAX are likely to be affected by SAD, while those with low MMAX are likely to persist as aspen habitat. We therefore used the median $MMAX_{2060}$ of this remaining aspen habitat in the GMUG area to divide it into THREATENED ($MMAX_{2060}$ > 24.68 C) and PERSISTENT ($MMAX_{2060}$ < 24.68 C) aspen habitat. To test this value under reference conditions, we evaluated a histogram of FIA plots in Colorado by MMAX of those plots during the reference period (Fig. 7). The median $MMAX_{2060}$ is above the mean, suggesting that it is a conservative estimate of the THREATENED habitat.

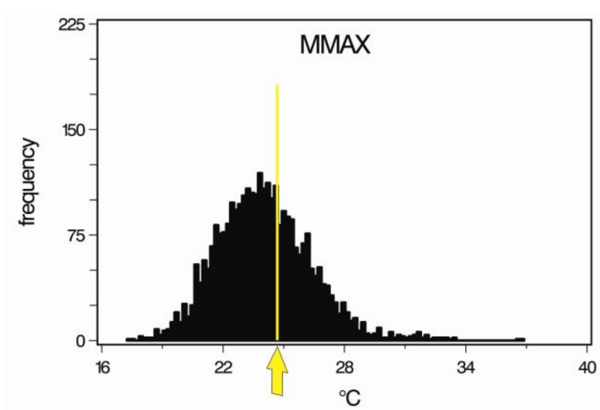

Figure 7. Frequency distribution of FIA plots in western USA that have aspen, versus the MMAX of those plots during the reference period (Rehfeldt *et al.* 2009). The indicated value is 24.68 C, the projected median value of the aspen habitat in 2060 that is neither LOST nor EMERGENT.

Given our topography, these four zones are distributed in a pattern predictable in part by elevation. In general, habitat will be lost at low elevations, especially on south aspects. At the opposite extreme, new habitat will emerge at elevations above the current distribution of aspen. The geographical distribution of the zones reflects this pattern (Fig. 8).

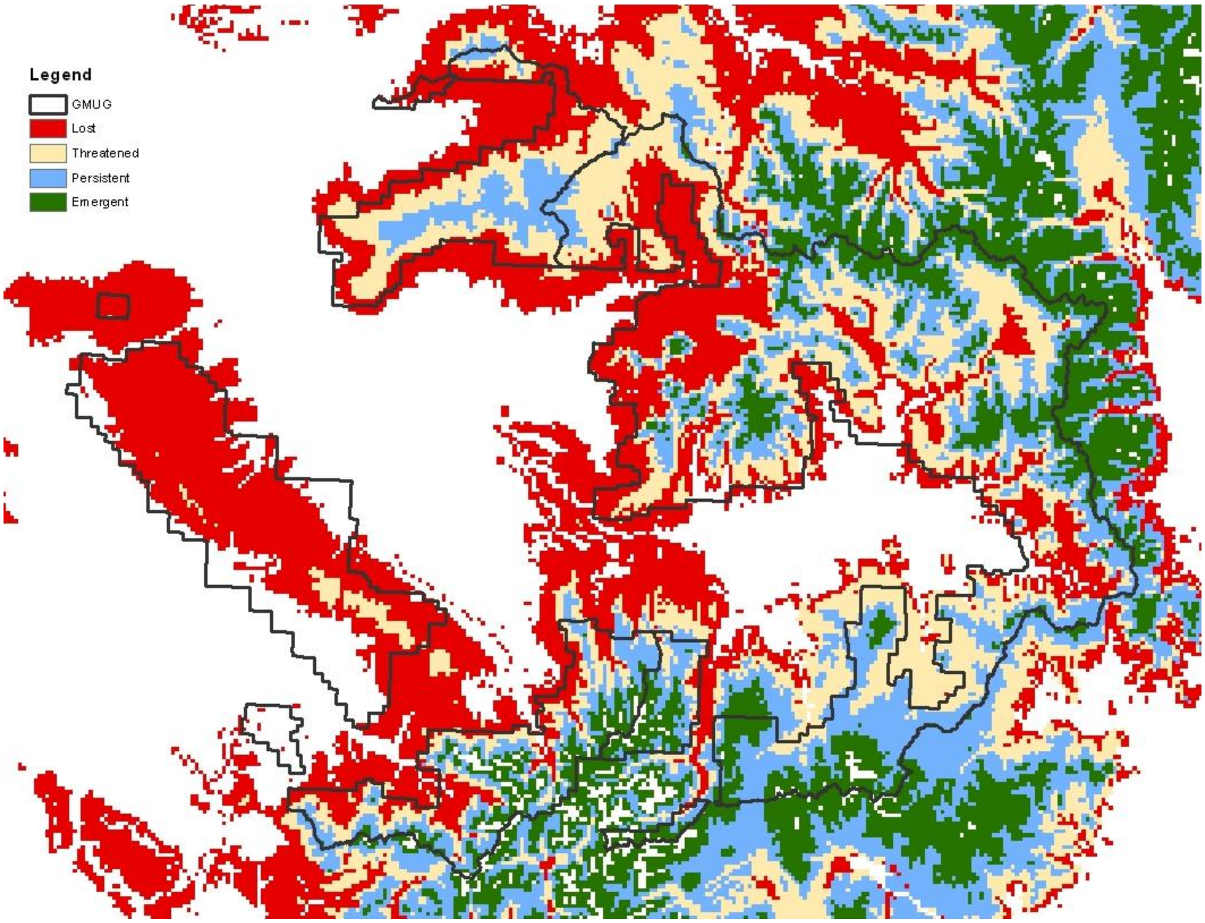

Figure 8. Future habitat zones of aspen.

2. Aid recovery of SAD-affected stands

As outlined above under Management Tools and Tactics, we can stimulate regeneration of SAD-affected stands before they decline beyond the point of no return, using either fire or mechanical treatment, as appropriate. Criteria for choosing stands for such treatments with this goal include: (1) Stands generally should not be in the LOST habitat zone, and in most cases will be in the THREATENED zone; (2) Stands should have estimated crown loss since the SAD episode began of about 50% or less. In cases where living trees have dieback and thin crowns, crown loss will be somewhat higher than mortality. Some of that loss will be represented by stems already on the ground; and (3) Stands should have existing regeneration density below a level deemed adequate by a silviculturist to generate an aspen stand similar in density and dominance to the stand before SAD, given overall vegetation conditions and herbivory pressure. Stands that already have adequate regeneration do not need to be treated for this goal.

3. Increase resilience of aspen

Because young aspen are resilient to drought, we can increase the resilience of aspen by diversifying the age structure on a landscape scale. The THREATENED habitat zone is the most appropriate place to implement this tactic, but in certain situations, similar treatments in the LOST zone may be appropriate. Because of the coarse model scale, there are likely sites within the LOST zone that will remain suitable in 2060. If the model were more fine-scaled and precise, these would perhaps be classed as THREATENED. Therefore, silviculturists should consider treatment of relatively mesic sites in the LOST zone that they judge as similar to sites in the THREATENED zone.

Distributing these patches widely, using fire where mechanical treatment is inappropriate, will help to ensure that a genetically diverse population is prepared to endure the extreme droughts anticipated to recur in the future. Otherwise, standard criteria can be used for selecting areas for treatment.

These treatments can be done in any cover type that has enough healthy aspen to provide good regeneration. Treatments of beetle-killed Engelmann spruce stands with scattered aspen would serve this purpose.

4. Facilitate self-migration of aspen

Facilitating the self-migration of aspen to emergent habitat has two components:

Preparing seed source. We should identify several large areas of EMERGENT habitat distributed around the GMUG, taking into account factors in addition to climate, such as soil. Then consider from where seeds could come to colonize the newly suitable habitat. The sources would be in nearby PERSISTENT habitat and generally upwind of the EMERGENT habitat. If there is abundant aspen in those PERSISTENT habitats, no action is needed. If there is aspen there at low density in mixed stands, regeneration treatments (fire or mechanical, as appropriate) should be considered to increase the future seed source.

Of course female aspen clones would be needed as seed sources. In addition, recent findings suggest that triploid aspen (with three sets of chromosomes rather than the usual two) occurs at a high frequency and occupies a substantial portion of western landscapes (Long & Mock 2012). Triploid clones are expected to have reduced sexual fertility. Based on current knowledge, they should be avoided when choosing areas to treat as seed sources. Testing for this is fairly quick and easy in a laboratory equipped for molecular genetics, and field or simpler laboratory methods for determining ploidy may be developed soon.

Preparing seedbed. In the identified large areas of EMERGENT habitat, stand-replacing fire or mechanical disturbance will enhance seedling establishment. Following disturbance, there is a window of about three years when aspen seedling establishment is potentially high. Once significant populations of sexually mature aspen are present as a seed source, managers should monitor disturbance events in the EMERGENT habitat. Wherever possible, wildfires should be allowed to burn in such areas. If wildfires do not occur, prescribed fire or mechanical treatment of existing vegetation should be considered to provide a seedbed. Much of the Emergent habitat will likely occur at high elevations in areas where mechanical treatment is inappropriate, so natural disturbance and prescribed fire will likely be needed. Treatment of beetle-killed Engelmann spruce stands in the EMERGENT zone as part of the EIS would serve to further this objective.

5. Adapt the strategy to extreme weather events

The strategy should be adaptive to extreme weather events that influence aspen, particularly extreme drought that incites another episode of SAD.

1. During favorable climate periods:
    a. **Resilience**: regenerate stands with an aspen component, primarily in THREATENED habitat zone, to increase younger aspen on landscape.
    b. **Recovery**: Treat previously affected SAD stands to aid recovery and regeneration, but not in the LOST zone.
    c. **Migration**: Conduct treatments and/or allow natural disturbances to proceed in the PERSISTENT and EMERGENT habitat zones in order to facilitate self-migration of aspen.
2. During extreme climate periods/SAD episodes:
    a. Prioritize **recovery** treatments of new SAD patches before canopy loss reaches 50%.
    b. Concentrate on the THREATENED habitat zone.

No Regrets

When considering strategies for adapting to climate change, a "no-regrets" strategy is one that is beneficial under multiple scenarios and has little or no risk of socially undesired outcomes (Vose *et al.* 2012). Such actions benefit resources and values regardless of climate-change effects. The present strategy is comprised of such actions. If future climate change is minimal, despite all the projections to the contrary, these actions will still provide age diversity in aspen populations, facilitate recovery of stands already affected by SAD, and allow aspen to flourish in treated stands where it is now yielding to conifers via succession. Together with that come all the benefits of aspen to wildlife, biodiversity, water, wood products, esthetics, and tourism. If, on the other hand, climate change is more extreme than the projections used here, we will have done the best that we currently can to provide for the conservation of aspen genetic diversity as well as that of the many associated species.

Conclusions

The proposed strategy is:

1. Based on well-defined objectives: resilience, recovery, and migration.
2. A strategy for determining where on the landscape treatments should be done to best achieve the objectives.
3. Consistent with common silvicultural and fire prescriptions.
4. Science-based. Many of the published studies, surveys and modeling that are incorporated into the strategy were conducted on the GMUG or include the GMUG.
5. Incorporates climate-change adaptation at a fundamental level.
6. A "no-regrets" strategy that provides benefits in a wide range of potential future climates.
7. Proactive in that it (a) improves **resilience** of aspen in advance of anticipated increased frequency of extreme weather, (b) provides for **recovery** of SAD-affected stands before they decline beyond the point of no return, and (c) prepares for **migration** of aspen to newly suitable areas.
8. Adaptive in the sense that it provides for climate-change adaptation of aspen forests, but also because the strategy adapts to occurrence of new episodes of SAD.

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Appendix: Accuracy and Uncertainty in Modeling and Projections

It should be recognized that there are limits to the accuracy of the methods employed, and to the certainty attached to projections of the future. While the bioclimate model is quite effective at replicating the distribution of aspen at large scales, at smaller scales errors of omission (predicting absence where aspen occurs) and commission (predicting presence where no aspen occurs) can be seen. For examples, errors of omission may occur when aspen is present in a small, suitable microsite in a grid cell that has, on average, unsuitable climate. Although the best techniques were used, interpolating or downscaling climate information cannot replicate actual geographic variation in climate with complete accuracy. Climate projections are based on a representative carbon pathway (RCP, i.e., emissions scenario) that may not represent the actual future trend in greenhouse gases. For example, conditions projected for 2060 may actually occur sooner if emissions are higher than projected by RCP-6.0, or later if they are lower. For these reasons, although boundaries between aspen habitat zones must be precise for planning purposes, ideally they should be regarded as the best estimate of fuzzy boundaries, and the timing of the projected changes as likely but uncertain.